NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

QUANTIFYING A NEGATIVE: HOW HOMELAND SECURITY ADDS VALUE

by

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December 2015

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** December 2015	**3. REPORT TYPE AND DATES COVERED** Master's thesis	
4. TITLE AND SUBTITLE QUANTIFYING A NEGATIVE: HOW HOMELAND SECURITY ADDS VALUE			**5. FUNDING NUMBERS**
6. AUTHOR(S) Eric Saylors			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB protocol number ____N/A____.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

Currently, fire department performance is measured in terms of tangible loss reduction, meaning lower dollar losses of tangible structures and contents equate with greater performance. This metric is flawed because it ignores the unmeasured performance of a fire department that saves nearby at-risk properties and businesses. Therefore, this thesis proposes a new metric: the saved ratio metric. It includes damages and business losses that may have occurred but did not, thanks to the suppression actions of an effective fire department.

The saved ratio is defined as the ratio of the value that was saved at an incident versus the value of what was at risk. The total value of what was saved is defined as the total amount of what was at risk minus the total amount of what was lost, and total at risk is quantified using a new network model of at-risk property. Adjacent at-risk property is cast into a network model whereby structures are nodes and adjacency or direct contact is represented by links.

Three major conclusions can be drawn from this study. First, the methodology of the real estate and economic industries can be used to quantify tangible and intangible value for structure fires. Second, network theory can be used to map the potential spread of a fire, allowing the user to identify which structures were saved or lost. Third, it is possible to estimate the return on investment added to the community from a fire suppression response model.

14. SUBJECT TERMS fire, public safety, fire loss, fire saves, fire value, value added, quantifying the negative, return on investment, save ratio, Sacramento Fire Department			**15. NUMBER OF PAGES** 83
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

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QUANTIFYING A NEGATIVE: HOW HOMELAND SECURITY ADDS VALUE

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Submitted in partial fulfillment of the
requirements for the degree of

**MASTER OF ARTS IN SECURITY STUDIES
(HOMELAND SECURITY AND DEFENSE)**

from the

**NAVAL POSTGRADUATE SCHOOL
December 2015**

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LIST OF ACRONYMS AND ABBREVIATIONS

EMS	emergency medical services
GRP	gross regional product
IRCA	inductive replace cost approach
MRIO	multi-regional input-output
NAIC	North American Industry Code
NFIRS	National Fire Incident Reporting System
NIST	National Institute of Standards and Technology
PFD	Phoenix Fire Department
QTN	quantifying the negative
REIM	regional economic impact model
RMS	records management system
ROI	return on investment
SFD	Sacramento Fire Department
SIAM	Society for Industrial and Applied Mathematics
UWI	urban wild land interface
WUI	wildland urban interface

VARIABLES

Σ_L	total loss
Σ_S	total saved
$\Sigma^T{}_V$	total tangible value
Σ_V	total value
IT_L	intangible fire loss
IT_V	total intangible value
T_L	tangible fire loss
TTV	total tangible value
T_V	total tangible value
S_R	saved ratio

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EXECUTIVE SUMMARY

How do agencies that prevent or mitigate disasters communicate their value? How do they justify their budgets? If one were to do a "return on investment" (ROI) study on homeland security departments, what value would they return? How would this value be expressed? The purpose of this thesis is to quantify the negative events (QTN) as well as the losses because "what was saved" is just as important (perhaps more important) as "what was lost." For example, the Great Chicago Fire of 1871 burned for three days, destroying thousands of buildings and killing an estimated 300 people to the tune of some $222 million in damages (more than $4 billion in 2015 dollars).[1] Legend has it the blaze started in a barn. If the fire had been stopped with only the loss of the barn, the value of the response would have been staggering—though the story might not resonate decades later. In fact, the true ROI of a fire department is the value of what was saved versus the cost of the fire department. This thesis quantifies what was saved and uses it to compute a ROI and a more meaningful representation of performance in the form of the S ratio.

A. BACKGROUND

One of the greatest challenges to public safety agencies is articulating and communicating their value in a quantifiable manner. This challenge is prevalent in most homeland security domains because their primary value is to prevent or mitigate events. In order to put a value on prevented and mitigated events, however, agencies must measure what did *not* happen. The standard strategy of public safety agencies is to measure and report the associated losses of events, which demonstrates the magnitude of the event more than it illuminates the effectiveness of the agencies tasked to prevent or mitigate events.

The fire service must change the dialogue by measuring, quantifying, and reporting the value of **saves opposed to losses** in a standard format. This thesis provides a general framework and specific methodology for quantifying the monetary value of

[1] Donald L. Miller, *City of the Century: The Epic of Chicago and the Making of America* (New York: Simon and Schuster, 1997), 159.

mitigating fires in an urban environment by focusing on structures and business that were saved due to the fire suppression activities.

B. METHODS

The method of analysis includes case studies of structure fires in an urban fire environment. Network theory is used to identify adjacent structures or units at risk during a fire, while economic impact theory and inductive replacement cost are used to quantify the value of at-risk structures and businesses. Network theory consists of nodes, links, and contagions, and it sets the bounds of what structures or adjacent units should be quantified as saved. By defining the fire as a network contagion that can travel to any node directly connected or within 10 feet of a contagion, this study clearly maps out incidents in a visual manner to allow the reader to quickly understand what structures were at risk during a fire.

Inductive replacement costs and economic impact theory are proven models for estimating value. Inductive replacement cost is used by the insurance industry to estimate the cost of rebuilding structures lost to fire. Economic impact models are commonly used by all levels of government to estimate the financial effects of an event on a region, such as the closure of a military base or the building of a new arena. Economic impact models include items such as sales taxes, local wages, and regional competiveness.

C. FINDINGS

The actions of the fire service explored in the four case studies resulted in more than $19 million saved. Based on the case studies, the projected return on investment for the cost of the Sacramento Fire Department exceeds 2200 percent—a number that would make any investor proud. The results show the true value of the fire service.

In addition, the new model developed in this thesis produces a more accurate representation of a fire department's performance by quantifying the ratio of what was saved. This save ratio functions as a comparable performance measure that can be used to evaluate the effectiveness of new policies or budgets. Ultimately, the save ratio can tell the fire department if it is improving or digressing in its ability to fight fires.

While the present study is restricted to structure fires, the general framework is expandable to such other fire service actives as emergency medical services, hazardous material responses, fire prevention actives, or special rescues. Furthermore, the logic of the framework may well have applicability in the homeland security realm beyond fire response. Together, the calculated return on investment and the save ratio produce a new metric of efficiency and effectiveness for the fire service.

D. CONCLUSIONS

As nudge to help other departments expand their performance measures to include what was saved, this thesis includes recommendations comprised of a vision, mission, and objectives. This thesis recommends that fire departments:

- Recognize that the worth of a fire department is greater than a calculation of loss and that including what is saved more accurately represents the worth of a fire department.
- Establish a standard to record and report the value of what is at risk and the value of what is saved on each fire, including tangible and intangible values.
- Use the save ratio as an internal comparative performance measure to help evaluate the effectiveness of policy changes.
- Use the total value of property saved versus the annual budget to calculate a return on investment for fire department.

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ACKNOWLEDGMENTS

I need to thank the prior generations of first responders who put their lives at risk to protect those who could not protect themselves. Your courage, dedication, and true brilliance under fire have laid the foundation for future generations to operate more safely and more effectively. My respect and admiration for the generations before me grow each day as I slowly comprehend the overwhelming challenges they faced with little to no acknowledgment.

My participation in the program would not have been possible without the direct support from Chief Lloyd Ogan. He recognized the value the NPS has to offer, and supported me when others in my organization did not. Any value that comes from this thesis should be partially credited to him and the efforts he made on my behalf.

Dr. Carolyn Halladay and Dr. Ted Lewis deserve a colossal "THANK YOU!" Dr. Lewis helped me to write my conclusions and abstract, and provided the entire foundation for my application of network theory. His kindness, understanding, and devotion to my success kept me moving. Dr. Halladay was my muse. She clarified my thoughts, organized my right-brain ramblings, and pushed me to step out of my comfort zone.

I have to thank my parents, Dave and Denise Saylors, who listened to my endless ideas about my thesis topic, proofread numerous editions, watched my children while I worked, and supported me in every way possible.

My deepest gratitude goes to my wife, Lisa, the most beautiful woman I have ever laid my eyes on. But her appearance pales in comparison to the understanding, compassion, and support she offers me. Left alone with two toddlers during the day while working nights in the ICU, Lisa never wavered in her support, but provided endless encouragement during my hardest days. Thank you, Lisa.

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I. INTRODUCTION

> Not everything that counts can be measured, and not everything that is measured counts.
>
> —William Bruce Cameron

Like most fire departments in the United States, the Sacramento Fire Department (SFD) has always used traditional methods of evaluating suppression performance, including response times, fire loss, and standards of coverage. However, these classical methods may fail to measure the economic value that SFD adds to the community. In other words, by its current methodology, SFD simply measures what is lost in fires not what is saved.

For example, in 2014, the SFD responded to a fire at The Door Store, a 10,000-square-foot warehouse full of 10,000 custom doors. The fire originated in a small shed attached to the warehouse. Suppression actions taken by SFD stopped the fire from entering the full warehouse. According to the conventional reporting method, SFD recorded a fire loss of about $1000, the value of the shed. However, SFD could have counted the value of the building and its contents of what was saved, a total of about $1 million. SFD reported a loss of $1,000, but it ignored the savings of $1 million. Because the event that was prevented or mitigated did not happen, it is a negative event. A negative event is an event that could have happened but was prevented by proactive intervention. The $1 million non-event is the value of a negative. The quantifying the negative (QTN) value is $1 million.

How do agencies that prevent or mitigate disasters communicate their value? How do they justify their budgets? If one were to do a "return on investment" study on homeland security departments, what value would be returned? How would this value be expressed? The purpose of this thesis is to QTN events as well as the losses, because "what was saved" is just as important as "what was lost." In fact, the true return on investment (ROI) of a fire department is the value of what was saved versus the cost of the fire department. This thesis quantifies what was saved and uses it to compute a ROI

and a more meaningful representation of performance in the form of the saved ration (S ratio).

A. PROBLEM STATEMENT

Imagine if General Motors headlined how many lives were lost in their vehicles each year. General Motor's stockholders, appalled by the negative news, would most likely question their investment. Fortunately for the future of the auto industry, General Motors instead can tout metrics that show its "value added," such as how many cars it sold and the resulting financial benefit.

So why do some homeland security agencies (e.g., the fire service) headline how much property was lost in fires? For the benefit of its investors, managers, customers, and the future of homeland security, wouldn't a better strategy be to headline metrics that show their "value added," such as how much property was saved and the resulting financial benefit?

To be sure, assigning a quantifiable value to what was prevented or mitigated is challenging. Homeland security agencies are faced with suggesting what could have happened and then assigning a value to the suggested event. This dilemma entails proving a negative, and many domains from medicine, to law, to statistics, to finance struggle with it. These sectors have their own tools for analyzing negatives, some of which may be applicable in homeland security, particularly to fire services.

In addition, homeland security agencies also must quantify the value of the event, essentially, quantifying a negative. Structures destroyed by fires have two basic values to the community: the tangible structure itself and the intangible values as the result of commerce that takes place in the structure. The tangible value of the structure can be directly reflected in how much it would cost to rebuild the structure. The intangible value includes such items as tax revenue, local jobs, inter-industry relationships, and local economic growth. This thesis investigates the use of the replacement cost approach and economic impact analysis to assess the tangible and intangible value of structures saved from destruction by nearby fires.

B. RESEARCH QUESTION

Current homeland security practice is focused on reducing risk, which is broadly defined as expected loss, or mathematically as R = VC, where R is risk, V is probability of loss to C, and C is typically measured in terms of dollars, casualties, or time. Return on investment (ROI) is positive only if the monetary cost of reducing V or C, or both, are less than the reduction in R. Practically speaking, this form of ROI can only be measured after the fact; that is, after the incident is over and losses are observed.

This measure of ROI has obvious flaws. For example, first responders, such as firefighters, have very limited control over V and C. More importantly, V and C are unknown for negative events. That is, no V and C are recorded for an event that does not happen. Consequently, "what was saved" is not currently included in the calculation of ROI.

Is a better measure of fire department success possible and desirable? This thesis proposes a new measurement of performance based on the saved ratio = (total at risk – loss)/total at risk, where total at risk is the sum of negative event consequence and loss and loss is the value of damaged property. Saved ratio incorporates what was saved, and therefore, it represents a better measure of performance.

Additionally, this thesis proposes a new model to identify what is at risk during fire incidents based on network theory. This model identifies at risk property based on network adjacency—nearby structures are linked to the burning structure. This firefighter's model represents buildings as nodes and adjacency as links. Thus, QTN is quantified by analyzing a network.

The goal of this thesis is to demonstrate that a comparable performance measure defined by the saved ratio is possible and a better measure of fire department success than the current practice of measuring only the tangible value of fire loss.

$$\text{Saved ratio} = (V-L)/V = QTN/V;$$

where V: Value of all at-risk property

L: Value of lost property

C. APPROACH

The main goal of this thesis is to change the paradigm of fire departments. Currently, fire department performance is measured in terms of loss reduction; that is, lower dollar losses equate with greater performance. This metric is flawed because it ignores the unmeasured performance of a fire department that saves nearby at-risk properties. Therefore, this thesis proposes a new metric, the saved ratio metric, which includes damages that may have occurred, but did not due to the actions of a competent fire department.

Measuring a non-event is difficult in most catastrophic circumstances; however, fire suppression effectiveness can be measured in the fire suppression services if we consider adjacent or nearby properties that did not burn but could have if there had been no response. This approach differs from existing approaches by quantifying what was saved as well as what was lost. The saved ratio quantifies effectiveness in terms of value rescued from fires as opposed to value lost.

The approach involves querying a major metropolitan fire departments' data for structure fires that involved businesses. Data are kept on the properties at risk due to their proximity to each other, type of construction, and tangible and intangible losses due to fire. For each incident, a saved ratio can be calculated based on the proximity of at-risk buildings. This thesis uses network theory to identify structures that are at risk to burning based on their relative exposure to a network contagion (i.e., independently burning). I computed dollar losses as the sum of losses due to structures and businesses taking place in the event using values obtained from the real estate and economics domain. Finally, the saved ratio is the ratio of total value at risk minus what was lost to total value at risk. The saved ratio is a measure of ROI that better describes the performance of a fire department.

Four case studies validate the model proposed by this research. Each case study shows the same methodology applied to different commercial fires, resulting a total amount saved and a saved ratio for each incident. By producing a post incident value of what was saved in a monetary format, the case studies demonstrate that calculating the saved ratio is not only possible, but it is also a better indicator of fire department performance than the current measurement of tangle loss.

D. LIMITS

The lists that follows outlines the limitations of what this thesis covers.

1. The following topics are out of the scope and would be single topics themselves:
    a. I am not considering forest fires or the urban wildland interface (UWI). Forest fires and UWI have already been greatly studied and exceed the scope of this thesis proposal.
    b. I am not considering the value of emergency medical services. Although this very important topic has great potential and forms a logical next step, its breadth would be best suited in a study solely dedicated to it.
    c. I am not considering the environmental impact of effective suppression activity. Once again, this very important topic would include so much material that it would be best suited in a study solely dedicated to it.
2. The following topics are excluded because they may be impossible to be known based on current technology.
    a. I am not considering the value of lives saved by self-evacuation. It would be impossible to know how many people left a hazardous building on their own once properly warned of the dangers prior to the fire service arriving.
    b. I am not considering the value of prevention efforts, such as building codes.
    c. The focus is response and suppression capabilities. Prevention efforts definably add value to the community, but without an event occurring to trigger a study, it is impossible to know what to study.
3. I am not considering the value of the contents of the structures, including the tangible, intangible, or sentimental value. Although I would love to quantify the value of the contents in structures, such as computers, files, furniture, etc., the ability to do so with a simple framework would

overwhelm this study. It would be a logic step, following the value of the structure and business, but it would require an additional study.

4. I am not considering noneconomic, intangible value of structures, such as historic or sentimental. Some structures' historic and sentimental value adds to, or far exceeds, their utility value, such as the White House. However, it is very hard to put a dollar amount on historic or sentimental value, so this study only includes the *replacement* cost of the *utility* of the structure and excludes any *replication* cost that may exceed the *utility*.

E. LITERATURE REVIEW

Does the fire service produce more that it consumes? One of the fire service's greatest **challenges** is articulating its value in a quantifiable manner because its primary value is to prevent or mitigate events. However, can the fire service measure what did not happen? A standard strategy of public safety agencies is to measure and report losses. I would like to change the narrative and to measure, quantify, and report our **successes** in a standard format.

F. PROVING A NEGATIVE

There is an abundance of literature on "proving a negative," ranging from theology to law. Most of the literature uses the term "proving a negative" as a philosophical cliché synonymous to an impossible act. However, in 1984 Kevin Saunders from the Michigan State University College of Law published an article entitled "The Mythic Difficulty in Proving a Negative." In this article, Saunders explains that there is no difficulty in proving a negative as long as the statement is logically formed. In addition, he suggests that universal propositions are more difficult to prove than existential ones.[1] For example, the statement, "Any structure fire will spread to the next building" is universal. In order to prove this statement, one must examine every fire in the universe to determine its tendency to spread to the next building. In contrast, an existential statement might hold, "A structure fire within 10 feet of another structure tends to spreads to the next structure." In order to prove this statement, one must only

[1] Kevin W. Saunders, "The Mythic Difficulty in Proving a Negative," *Seton Hall Law Review* 15 (1984): 276–289, http://digitalcommons.law.msu.edu/cgi/viewcontent.cgi?article=1426&context=facpubs.

examine a sample of structure fires in structures within 10 feet of each other and observe the relevant trends.

Although Saunders did not answer the typical questions posed around proving a negative, such as the existence of God or whether absence of evidence is evidence of absence, this article is highly relevant as a framework to create a defining existential statement of what structures are at risk from fire spread. In other words, Saunders helps us create measurement criteria without loopholes.[2]

G. DEFINING WHICH STRUCTURES SHOULD BE CONSIDERED FOR EVALUATION

One of the key questions of this thesis is how far away from a burning structure another building must be in order to be included in the framework. In other words, if a structure fire's spread is suppressed to one building, is it fair to take credit for saving the entirety of city, the block, or just the immediate neighboring buildings?

The transmission of fire from one structure to another is affected by many factors including separation distance, construction type of the structures, placement and size of windows in the structures, and weather.[3] Many studies and publications examine fire spread of closely spaced buildings, including "On Radiant Heat Transfer from Turbulent Flames" by Cox.[4] Cox's publication is the start of a simplified theoretical model to determine a flame's radiations hazards,[5] in other words positing the shape of the flame effects how much radiant heat is put out. This study was the foundation for modeling fire spread in urban and wildland environments.

In 2002, Himoto and Takeyoshi added to the body of knowledge with "A Physically Based Model for Urban Fire Spread," which developed a model for the "ideal

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[2] Ibid.

[3] Alex Maranghides, and Erik Johnsson, *Residential Structure Separation Fire Experiments* (Technical Note 1600) (Washington, DC: National Institute of Standards and Technology, 2006).

[4] Gordon Cox, "On Radiant Heat Transfer from Turbulent Flames," *Combustion Science and Technology* 17, no. 1–2 (1977): 75–78.

[5] Ibid.

urban district and the building-to-building fire spread."[6] The model simulated a structure fire allowed to burn in an urban city without suppression activities. The 49 identical structures were two-story residential buildings spaced 10 feet apart. A small fire was started in the first story hallway at the base of the stairs. A single structure fire eventually spread from building to building, consuming all 49 structures in the model.[7]

The model was intended to evaluate fire losses in a post-earthquake environment where fire suppression services are disabled. In addition, all of the structures where assumed to be wood, which is not an accurate representation of most urban cities in the United States. Also, the start of the initial fire at the bottom of the stairs is the prime location to start a fire in order to promote spread in a structure and realistically a very unlikely place for a non-arson fire to originate. The authors point out that the model was in an exploratory stage and admitted it required refinements.[8] Nevertheless, the results are scientifically valid, taking into consideration wind speed and direction, window openings, moisture content, thickness of materials, thermal conductivity of materials, and heat of combustion. The study vividly displays the propensity of fire to spread in an urban environment without aggressive suppression activity.[9]

Building on this concept, the National Institute of Standards and Technology (NIST) published a study in 2006 entitled *Residential Structure Separation Fire Experiments*.[10] The study consisted of two wooden homes placed six feet from each other. NIST conducted two experiments by building two sets of adjacent homes within six feet of each other. The first set of homes was built to standard construction code without fire resistant construction. In one home a small fire was started in the common area, and the time it took to ignite the adjacent home was recorded. The second set of homes was built with a fire resistant barrier in the wall. In this experiment, the second home ignited from flames in less than 80 seconds without fire resistant construction. The

[6] Keisuke Himoto, and Takeyoshi Tanaka, "A Physically-Based Model for Urban Fire Spread," *Fire Safety Science* 7 (2003): 129–140, http://www.iafss.org/publications/fss/7/129/view/fss_7-129.pdf.

[7] Ibid.

[8] Ibid.

[9] Ibid.

[10] Maranghides, and Johnsson, *Residential Structure Separation*.

home with fire resistant construction lasted for six minutes before igniting. The point of the experiment was to demonstrate that fire resistant construction can significantly increase the time flames spread in urban communities, allowing time for the fire department to respond.[11]

The methodology of the NIST experiment is valid, and the results are predictable and reproducible. The value of the NIST study is the verification of the rapid fire spread in urban cities; however, the shortcoming of the NIST study was it only included wooden homes. Even the study states, "the spread of fire from one structure to the next is governed by four things: **Construction type**, placement and size of windows, proximity of structures, and wind."[12] Further studies need to be completed to include other construction types, such as masonry; however, even with the shortcomings, the results of fire spread from structure to structure in 80 seconds is compelling and freighting.

In 2008, Guanquan and Jinhua published "Quantitative Assessment of Building Fire Risk to Life," a framework to evaluate fire risk to life safety. They divided the concept of fire risk into a framework of probability and consequence. The resulting framework predicted the probability of fire spread based on time. The premise of the study is that when the time required to reach an un-survivable temperature, based on a probability distribution, is greater than the time required to evacuate a structure, based on a probability distribution, then life is at risk. A one-story, 56,000-square-foot commercial building with 28 rooms is included as a case study.[13]

Although the main point of the article by Guanquan and Jinhua was life risk, it does a good job of defining the probability of fire spread, which is essentially what I am looking for. Granted, the framework presented is forced to make assumptions on many variables used in the fire spread model, but the assumptions are reasonable and produce predictable results.[14]

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[11] Ibid.

[12] Ibid.

[13] Chu Guanquan, and Sun Jinhua, "Quantitative Assessment of Building Fire Risk to Life Safety," *Risk Analysis* 28, no. 3 (2008): 615–625.

[14] Ibid.

The research suggests that in a highly dense city, such as Sacramento, with minimal space between structures and a high density of trees, fire spreads from structure to structure without intervention of suppression actions can be assumed as highly probable. The challenge is solving the question of how far do structures need to be away from the source of heat before they are not considered at risk. For this analysis, we must turn to wildland studies focused on the wildland urban interface (WUI), areas where homes are built near lands prone to wildland fires. Multiple studies have been published on fire spread in WUI areas. The Society for Industrial and Applied Mathematics (SIAM) modeling and case studies indicate that any wooden structure within 130 feet of significant flames is susceptible to ignition.[15] Once again, only wooden structures were considered.

Until further studies update this distance, 130 feet seems be the standard used to determine what structures are affected by radiant heat.[16] Therefore, any immediate wooden structure within 130 feet of the building of fire origin without a barrier to the radiant heat can be considered at risk. Further research is needed to fine tune this number and take into consideration the type of structure (e.g., wood, steel, masonry).

H. TANGIBLE VALUE

One accurate measurement is worth a thousand expert opinions.

—Admiral Grace Murray Hopper, 1906–1992

The tangible value of the structure can be expressed as how much it would cost to rebuild the structure. This value figures into a framework common to the real estate and insurance industries known as the cost approach. The cost approach of estimating a structure's value is a standard in the insurance and real estate appraisal industry. The insurance industry uses replacement cost as the primary factor in insurance pricing decisions.[17] The inductive replacement cost approach (IRCA), an abbreviated form of the

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[15] Jack D. Cohen, "Preventing Disaster: Home Ignitability in the Wildland-Urban Interface," *Journal of Forestry* 98, no. 3 (2000): 15–21.

[16] Ibid.

[17] Scott Amussen, "3 Tips to Real Replacement Costs," *Property & Casualty* 360 (July 2011).

cost approach based on average regional prices, is used in the insurance industry for the purposes of proper insurance amount, determining agreed amounts, coinsurance requirements, and claim settlements.[18] In the real estate industry, the cost approach is the foundation for all worth from which that market value and income value spring.[19] Additionally, the replacement cost is a mandatory tool when evaluating properties that do not enter the market frequently.[20]

The replacement-cost is based on the utility of the structure and is the approximate cost to rebuild a structure of similar utility. Replacement-cost estimates exclude land value and detached structures on the property and vary based on difference in local building materials, labor, and equipment used in reconstruction.[21] As opposed to the reproduction cost, which is the cost of rebuilding an exact duplicate of the structure, estimating replacement costs are "less taxing, less vulnerable, and less artificial than reproduction cost estimates" and can eliminate most super adequacies (improvements that do not return their cost) from assessments and value estimates.[22]

The four methods for determining replacement cost are: quantity-survey method, comparative method, trending method, and inductive method (i.e., IRCA). Professional appraisers use a detailed form of the inductive method, but it adapts well to being used in a non-detailed form. The non-detailed form is based on a model that estimates building cost calculated a base date and at a base location. The time and location multipliers are regularly updated to keep the costs current, so that the user can arrive at a current value for a building in any geographic location with limited work.[23]

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[18] Ralph M. North III, "Replacement Cost Estimating for Non-Professionals," *The National Underwriter* 84, no. 47 (1980): 24.

[19] Max J. Derbes Jr, "Is the Cost Approach Obsolete?" *The Appraisal Journal* 50, no. 4 (1982), 581.

[20] Ibid.

[21] Scott Amussen, *3 Tips to Real Replacement Costs* (New York: National Underwriter Company dba Summit Business Media, 2011).

[22] Romain L. Klaasen, "The Replacement Cost Shortcut," *The Canadian Appraiser* 34, no. 3 (1990): 26–29.

[23] North III, "Replacement Cost Estimating for Non-Professionals," 24.

I. REGIONAL ECONOMIC IMPACT MODELS

Regional economic impact models (REIM) are used to estimate and quantify the economic responses in a regional economy. For example, if a city builds a sports arena, REIM can estimate the new development's effect on income, employment, and output (the amount of production including goods purchased and value added) in the regional economy. REIM is more widely used than any similar model, is available in explicit detail in publicly accessible papers, and its methodology is completely public.[24]

The major criticism of REIM is its use or misuse. Edwin Mills, author of the "Misuse of Regional Economic Models," claims, "economic analysis is sometimes used selectively and prejudicially to support to support, ideology and self-interest of state and local government officials." [25] Mills describes how regional economic models systematically exaggerate the public benefits of government projects, thus encouraging excessive government spending in areas that should be left to the private sector. [26] Because the model ignores the cost of raising public funds and counts construction wages as benefits opposed to costs, the model permits users to exaggerate the public benefit of government projects.[27]

Mills breaks down the model and explains how REIMs worked in 1993. Granted, REIM models have evolved since Mills published his article, but his point still stand true; the model can still be misused. Mills himself admits this in his article; however, he does not fault the model itself but rather the miss application of it. REIM still has incredible value in evaluating private projects; however, when used by a government agency to support a project, extreme bias may be expressed in the results.[28]

REIMs have been used to study a wide variety of economic impacts, including bio-diesel industry in New York, military base closures, life sciences plant in California,

[24] Edwin S. Mills, "The Misuse of Regional Economic Models," *Cato Journal* 13 (1993): 29–40.

[25] Ibid.

[26] Ibid.

[27] Ibid.

[28] Ibid.

and large housing projects in Pennsylvania.[29] Furthermore, in 2011, the Phoenix Fire Department (PFD) used a REIM to conduct a comprehensive study on of the economic impact of fire suppression operations on a fire.[30] PFD trained its employees to recognize and tag incidents that represent a "fire save."[31] The data from the incident was sent to Arizona State University and applied to an Arizona-specific version of REIM for analysis of the economic impact if the business was lost. Following up the initial study in Phoenix, Dr. Evans at the Arizona State University conducted a new study of commercial fires over a period of three months, from June 1, 2012 to August 31, 2012, which included eight commercial fires affecting 13 businesses.[32] Dr. Evans used a REIM model developed by Regional Economic Models Incorporated, specifically the Policy Insight Version 1.3.13. The results of the study are profound, including the loss prevention of 2,322 jobs, 196 million in gross state product, 94 million in real disposable personal income, and 10 million in state tax revenues.[33]

Regional productivity and competiveness is one of the main metrics REIM tries to measure and forecast. REIM's categorizes businesses by the North American Industry Classification System (NAICS),[34] which is the "standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy."[35] REIMs typically operate at three different levels the NAICS system, ranging from 160 sectors to 23 sectors—the later having much less specific results than the former. Dr. Evans does not disclose which version he uses to estimate the value saved from the suppression

[29] "The REMI Model 'Topic Areas' Economic Development," Regional Economic Models, accessed September 15, 2015, http://www.remi.com/the-remi-model/topic-areas/economic-development.

[30] Timothy Kreis, "The Economic Impact of Firefighting: A New Way to View Firefighter Service," *Fire Engineering* (August 2013): 83, http://www.fireengineering.com/articles/print/volume-166/issue-8/features/the-economic-impact-of-firefighting-a-new-way-to-view-firefighter-service.html.

[31] Ibid.

[32] Anthony Evans, *The Economic Impact of Successful Commercial Fire Interventions* (Tempe, AZ: William Seidman Research Institute, 2013).

[33] Ibid.

[34] Rod Motamedi, REMI economist, interview with author, 2014.

[35] U.S. Census Bureau, "North American Industry Classification System," accessed October 18, 2015, http://www.census.gov/eos/www/naics/.

activities, nor does he disclose how the REIM extrapolates a simple NAICS code to achieve such specific results. However, he does state, “The REMI model is recognized by business and academic community as the leading regional forecast/simulation tool available.”[36] Unfortunately, to a skeptic, this statement does nothing for the accuracy or validity of the model and is akin to saying “well everyone else is doing it.”

Pursuing my skepticism, I was not able to find any publication on the accuracy or validity of the REIM model; however, I did find the 2005 thesis by a University of Texas at El Paso student, America Tirado, titled “A Sensitivity Analysis of the REMI Model.”[37] In his thesis, Tirado explains that the REIM model makes certain assumptions about the environment that may not apply to all regions and can be manipulated by the user with negative effects.[38] Additionally, he clarifies that a user can spend more time learning to correctly adjust the assumptions in the model than analyzing the results of the model itself. Moreover, he states that while most of the assumptions are true at a national level, the result can differ at a smaller regional level.[39] For example, a growth multiplier at a national level may not be as large at a small regional level that must outsource much of the assumed extra growth in the multiplier, overestimating the effect on the smaller region.

Tirado’s assessment of the REIM model is thorough, leaving the reader with a very good understanding of how the model works and what limitations it has. Furthermore, even though the intent of the thesis was not to gauge the accuracy of the model, Tirado’s explanation boosters’ confidence in the validity of the REIM model by explaining the economic theories it is base on.

[36] Evans, *The Economic Impact of Successful Commercial Fire Interventions*.

[37] America Tirado, “A Sensitivity Analysis of the REMI Model” (master’s thesis, University of Texas at El Paso, 2005).

[38] Ibid.

[39] Ibid.

J. MEASURING EFFECTIVENESS

Once a "number" representing the tangible and intangible value of a structure is generated, should be done with it? In September of 2006 as his doctoral dissertation, U.S. Air Force Major Richard Bullock published and exhaustive document entitled, "The Theory of Effectiveness Measurement," which established a framework for measuring effectiveness in theory and practicality.[40] Starting from accepted effects-based principles, Bullock creates a general methodology to measuring effectiveness or intended change to the system. Finally, Bullock applies his framework to a theoretical response to a terrorist attack.

Measurement theory indicates the need for both a nominal number, the total sum of the tangible and intangible values in order to prove an agencies worth in dollars and cents, and a ratio to compensate for the differing magnitudes of the sums. The ratio, or the "S ratio," can show what was saved from the total of what was at risk.

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[40] Richard K. Bullock, "Theory of Effectiveness Measurement" (AFIT/DS/ENS/06-01) (dissertation, Air Force Institute of Technology, 2006).

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II. METHODS

The objective of "quantifying the negative" (QTN) is to summarize a prescriptive framework that produces a metric for structure fires in an urban environment based the dollar amount of what was saved. In its broadest form, the framework consists of a two-step process: 1) identify using network theory, and 2) quantify monetary value using inductive replacement cost and economic impact models. The "identify" step requires appropriate qualifiers defining an existential statement in order to limit the scope of study subjects. The "quantify" step uses tools from the real estate and economics industry to produce a dollar value for structures and businesses.

The data for the case study was selected from the Sacramento City Fire Department Records Management System. Fires involving commercial structures from 2009 to 2016 were selected based on the completeness of the report and business data available. In addition, the data from the fires were run through the proposed framework of identify and quantify to produce both a total dollar amount of what was saved and a performance ratio (the S ratio) of what was saved over the sum of what was at risk.

A. SETTING

The study took place in Sacramento, California using the Sacramento Fire Department (SFD). Sacramento is the capital of the state of California, the county seat for Sacramento County, and the central city for the four-county Sacramento metropolitan area. Sacramento is 99.2-square-miles, which 97.2 miles are land and two miles are water.[41]

Following 1800s Gold Rush and a series of devastating fires that consumed most of the city, Sacramento Fire department (SFD) was formed in 1850. The SFD now consists of roughly 600 employees and 24 stations and responds to roughly 80,000

[41] Sacramento Fire Department, *2012–2017 Sacramento Fire Department Strategic Plan* (Sacramento, CA: Sacramento Fire Department, 2012), http://portal.cityofsacramento.org/~/media/Corporate/Files/Fire/Reports/Sacramento-Strategic-Plan-FINAL-DOC.pdf.

dispatches a year. SFD’s urban fire spread potential is increased by an average housing density of 1907 units per square mile and an average of 4660 people per square mile.

B. PARTICIPANTS—SAMPLING PLAN

SFD suppresses about 400 major fires a year, including fires in homes, apartments, shopping malls, high-rises, warehouses, business offices, and open fields (grass/wildland fires). The fires for the case studied were selected from the SFD records management system (RMS) using a purposive sample. The fires were selected base on the report classification, the location, and businesses involved. Every 911 response is categorized and logged into the RMS as a report. The fire were selected from the category “111,” which is a National Fire Incident Reporting System (NFIRS) defined category for “building fire.”

The selection of fires was then limited to incidents that occurred in SFD’s justification and included a commercial structure housing a retail business. I choose retail business for the ease of collecting accurate and relevant data that would use every aspect of the framework for demonstration purposes. For future studies, such restrictions should be removed to include all building fires.

C. MEASUREMENT INSTRUMENTS

The primary measurement tool was the risk equation, based on Daniel Bernoulli’s *expected utility theory* (EUT).[42] EUT defines risk (R) as expected loss, or the probability (P) of an event with negative or positive consequences (C): R=P*C. The focus of QTN is the resulting change in consequences (C) due to a fire suppression response. Consequences is defined as the data from IMPLAN and 360Value.

1. Measuring and Defining Consequences

The primary measurement instrument in measuring consequences, or value of what may be lost or gained, was an online replacement cost software called “360Value,” which is owned and operated by Verisk Analytics, a risk assessment and decision

[42] Ted G. Lewis, *Critical Infrastructure Protection in Homeland Security: Defending a Networked Nation* (Hoboken, NJ: John Wiley & Sons, 2006).

analytics company.[43] The decision analytics tools and services of Verisk Analytics include predicting future losses, quantifying losses that have already happened, property insurance, fire risk, financial services, and selecting and pricing risk.[44] 360Value is an underwriter tool used to make insurance policy decisions based on the replacement-cost of residential and commercial structures. The replacement cost estimates from 360Value come from the actual repair costs of 75 million properties across the U.S. Additionally, 360Value uses 17 main characteristics to classify and group properties in its database,[45] it provided the tangible value estimate for the buildings identified in the study based on its unique variables.

The secondary measurement instrument was IMPLAN, an economics analysis tool used to examine local economies and predict financial impacts due to business changes in the region. IMPLAN is an input-output model that provides a valuation of local economies, including gross regional product (GRP) defined by value added or final demand. IMPLAN considers the major producers in the region and factors such as employment, labor income, taxes, and profits. IMPLAN can be used to identify areas in the region that should be targeted for the growth of the economy or to support existing businesses. In addition, IMPLAN uses a multi-regional input-output (MRIO) analysis that allows the user to see the interlink ages from one economy to those economies around it. Ultimately, IMPLAN can estimate the dollar value of a local business to its community. IMPLAN was used to estimate the intangible value of businesses identified in the study.

D. PROCEDURES

For the research, I accessed each fire for the exposures it threatened based on the selection criterion of 10 feet from the source. In other words, I identified and quantified a structure within 10 feet of the source. Using network theory to map out and identify structures threatened by the source fire, I gathered the independent variables from each structure and feed them into the 360Value model and the IMPLAN model. Some of the

[43] "About Verisk," Verisk, accessed June 7, 2015, http://www.verisk.com/about-verisk.html.

[44] Ibid.

[45] "Xactware Products." Verisk, accessed June 7, 2015, https://www.xactware.com/en-us/products/.

variables were already included in the fire report in the SFD's RMS. I gathered the remaining variables by a site visit.

1. Identify

Burning structures, groups of burning buildings, and buildings with multiple units come in many shapes and sizes. Identifying the spread of a fire via a ubiquitous framework may be a challenging concept in some situations. It is not reasonable to simply say any building within a certain distance should be included. Therefore, this study used network science to clearly map out complex incidents to identify structures or parts of structures at risk.

Network science is a simple framework for modeling complex systems into nodes and links laid out on a topographical map. This is the basic framework QTN used to model fires and identify the structures to be quantified. A basic introduction to network theory will allow the reader to understand how and why to map a complicated fire.

a. Clustered Nodes and Links

Nodes are simply the units, parts, or subsystems of a network.[46] For example, a neighborhood block of 10 homes could be considered to have 10 clustered nodes just as a high-rise of 400 residential units has 400 tightly clustered nodes. Links are the pathways between nodes,[47] similar to how a wooden fence may directly connect one home to another in an urban neighborhood or an airduct may connect one unit to the next unit in an office building.

Nodes and links in metropolitan environments tend to organize into tight groups and conform to cluster networks. Clustered networks have no specific link distribution, but instead, their nodes are tightly connected to one other in local groups,[48] just like a city block, an apartment building, or a high-rise building. Cluster coefficient, or the likeliness of one node being connected to many nodes in the system, tend to be high in

[46] Lewis, *Critical Infrastructure Protection in Homeland Security*.

[47] Ibid.

[48] Ibid., 65.

clustered networks because the nearest neighbors of the nodes are connected to each other in each cluster—just a one neighbor backs up to the next neighbor in a city block. Additionally, separate clusters are connected to one other via long distance links, such a street or vacant lot. So just like the grid of a dense city, cluster networks are groups of nodes tightly packed together and connected to other groups of node via a longer gap or link.

b. Network Contagion

A network contagion represents the spread of an undesired status or pathogen in a network from node to node via connectors, similar to influenza in a schoolyard, a computer virus over the internet, or a wildfire in a forest. Moreover, just as a contagion infects a single node in a clustered network and then spreads via the links to other nodes, a fire starts in a single building or unit and spreads to the neighboring buildings or units in the block or cluster. Spreading fire will be viewed as a contagion spreading across the network of building or units.

Just as a fire consumes a city block if not stopped, cluster networks are vulnerable to a cascading collapse via a spreading contagion due to the high level of connectivity. Removing or isolating contaminated nodes from the rest of the network stops the spread of a contagion. Essentially, the fire service isolates network contagions or by removing and isolating contaminated or burning nodes.

c. Defining a Node

This study uses nodes, such a building, tree, car, or an isolated unit in a building (e.g., an apartment or shop in a strip mall), to represent combustible material that can sustain and spread fire.

d. Defining a Link

This study used a distance less than 10 feet to define a link from one node to the next. Since fire spread is facilitated by radiate heat, convection heat, and conduction heat, no physical connection is need. The only real limiting factor in the ability for fire to spread is distance from node to node. Therefore, any distance less than 10 feet was

represented as a link from one node to the next as supported by "a physically-based model for urban fire spread"[49] and the "2013 California Building Code, §705, fire separation distance."[50]

e. Modeling the Fire Incident as a Network

Networks can be modeled or mapped out into a topographic map of the nodes and the links. Nodes are typically drawn as squares or circles while links are typically lines from one node to the next. When modeling an incident starting from a node or cluster of nodes, the height of the model must be determined. The height of the model is how many hops from the original node will be mapped with the model. For example, a network model height of one would map the original node and then all nodes connected directly by one link, or the immediate neighbors (see Figure 1). A network model height of two would map the original node, all the immediate neighboring nodes connected by directly by one link, then all node connected to the immediate neighboring nodes and so on (see Figure 2). Every case study in this thesis used a network height of one to model the network. In other words, the study only quantified the building in immediate exposure to the fire and did not consider buildings beyond the immediate neighboring buildings.

[49] Himoto, and Tanaka, "A Physically-based Model for Urban Fire Spread," 14–15.

[50] Public Code, "Maximum Area of Exterior Wall Openings Based on Fire Separation Distance and Degree of Opening Protection," accessed September 15, 2015, http://publicecodes.cyberregs.com/st/ca/st/b200v10/st_ca_st_b200v10_7_sec005.htm.

Figure 1. Network Model (Height of One)

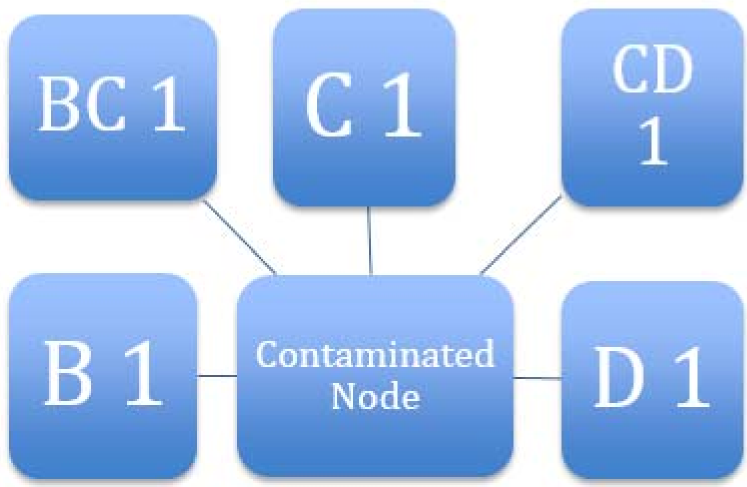
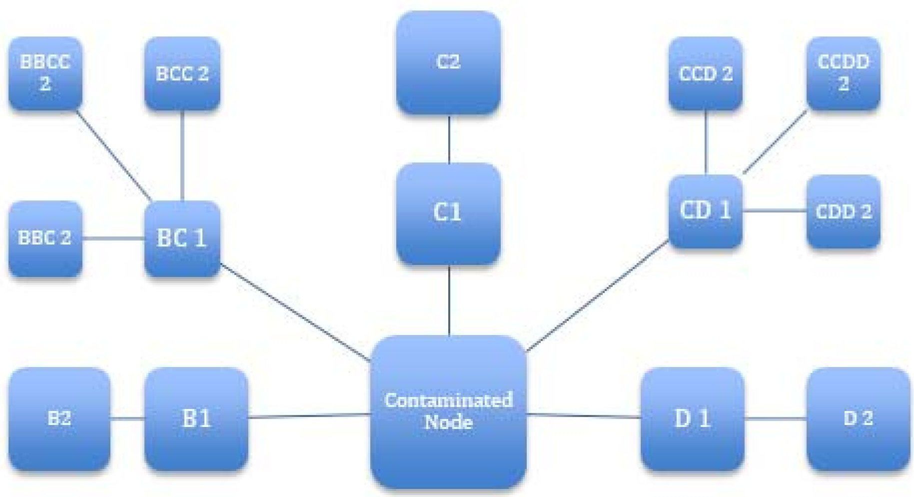


Figure 2. Network Model (Height of Two)



The following steps were used to identifying quantifiable nodes:

1. Determine the height of the network model (e.g., height of one for this study)
2. Build a topographic map of the incident
3. Count the nodes

4. Count the links
5. Identify the contaminated or burning nodes
6. Identify and count the nodes linked to the contaminated nodes one height away
7. Quantify the contaminated and connected nodes using the tangible and intangible models.

I used network theory, based on a one-height model and link defined as a distance of 10 feet, to determine what nodes would be included into the study and what category the nodes would fall into: contaminated or saved. Nodes that sustained combustion from a fire were defined as contaminated. I categorized nodes linked one height away from the contaminated nodes as at-risk. In addition, I considered any business in the network model that was unable to reopen within 30 days an intangible loss. Any business in the network model that stayed open or reopened within 30 days counted as an intangible save. Table 1 shows the categories of losses vs saves used in the study.

Table 1. Loss/Save Categories

Tangible Loss	Transcribed from Incident Report
Intangible Loss	Any modeled business unable to reopen in 30 days
Tangible Save	One height from a contaminated node
Intangible Save	Any modeled business able to reopen within 30 days

2. Quantify

Value is categorized into either tangible or intangible value. Tangible value is defined as the replacement cost of the structure while intangible value is defined as the economic value of the business.

a. Tangible

Tangible value was determined using an inductive replacement cost software package called 360Value. The variables required for 360Value are based on their construction, including height, square footage, exterior and interior wall type, number of windows and doors, fire protection systems, heating and air conditioning systems, roof

type, etc. Each structure was cross-referenced with the county tax assessor's office to determine and confirm year build, square footage, and major improvements. From there, the study gathered as many relevant variables as possible during a site visit with the understanding that most of the numbers generated for replacement cost would be conservative.

The variables were entered into 360Value to get a tangible value (T_V) for each building on the network map expressed as replacement cost. Tangible value loss from fire (T_L) was transcribed from the SFD records management system incident report "property loss" field.

b. Intangible

The intangible value was determined using an input-output economic impact model called IMPLAN. IMPLAN requires two variables once the model is set up: the number of employees and the North American Industry Code (NAIC) of the business. Based on the NAIC and the number of employees, IMPLAN estimates the economic impact to the region expressed as "value added" and "final demand" in the form of gross regional product (GRP). Gross regional product is defined as "the market value of all final goods and services produced" within the region over a period.[51] IMPLAN calculates GRP through "scenarios," which can include a change to one or multiple businesses.

Each business modeled in IMPLAN was cross-referenced with SFD's fire prevention data to determine and confirm usage and business type. In addition, each business was visited to confirm the number of employees and NAIC. Building the model and scenario in IMPLAN requires a study regions defined by state, county, or zip code, and an "activity type." This study used the Sacramento county region and the "activity type" of "industry change." "Industry change" was selected to quantify the impact to the region of the business's on the network model were to leave the industry.

Impact scenarios were created for each business by analyzing a scenario where all employees who work the business are removed from the related industry sector for one

[51] "Gross Regional Product," Lawrence Consulting, accessed November 3, 2015, http://lawrenceconsulting.com.au/le/2241c42d-68a4-438f-ab0d-86d4751db74a/grossregionalproduct.html.

year. The result is a negative total GRP for the region. The GRP was used to define the intangible value of the businesses.

The NAIC codes and the number of employees were input into the IMPLAN model as a single scenario to determine the total intangible value ($\Sigma^{T}{}_{V}$) of all the businesses, regardless if they were able to reopen within a month. This was done to establish a total intangible value ($\Sigma^{IT}{}_{V}$) of all business at risk expressed in GRP.

Intangible loss from fire (IT_L) was calculated separately in IMPLAN, expressed as a loss to GRP for businesses that did not reopen within a month. Intangible loss from fire was calculated separately so it could be combined with total tangible loss in order to show total loss. The parameter of one month was selected because frequently buildings that experience a fire loss access to utilities. Utilities are typically restored within two weeks, allowing the surviving business to reopen. If the business is not reopened after a month, it is not a utility problem and the business has likely suffered enough damage that it will not survive.

E. DATA ANALYSIS

The collected data was transcribed and categorized using the network model in terms of total tangible value (T_V), total intangible value (IT_V), tangible fire loss (T_L), and intangible fire loss (IT_L). All of the tangible values were totaled to calculate total tangible value (TTV).

$$\text{TV}=\sum_{k=1}^{n} TVk$$

The total tangible value ($\Sigma^{T}{}_{V}$) and total intangible value (IT_V) were totaled to calculate total value (Σ_V). The tangible fire loss (T_L) and intangible fire loss (IT_L) were totaled to calculate total loss (Σ_L).

$$T_L + IT_L = \Sigma_L$$

The total loss (Σ_L) was subtracted from the total value (Σ_V) to calculate total saved (Σ_S)

$$\Sigma_V - \Sigma_L = \Sigma_S$$

A normalized ratio was calculated for the purpose as comparable performance measure. The total saved was normalized by dividing Σ_S by total involved (Σ_V) to produce a saved ratio (S_R).

$$\Sigma_S \div \Sigma_V = S_R$$

Finally, the results I used to quantify a shift in consequences by comparing what the total value lost to the fire versus the total value of what was at risk due to the fire.

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III. RESULTS

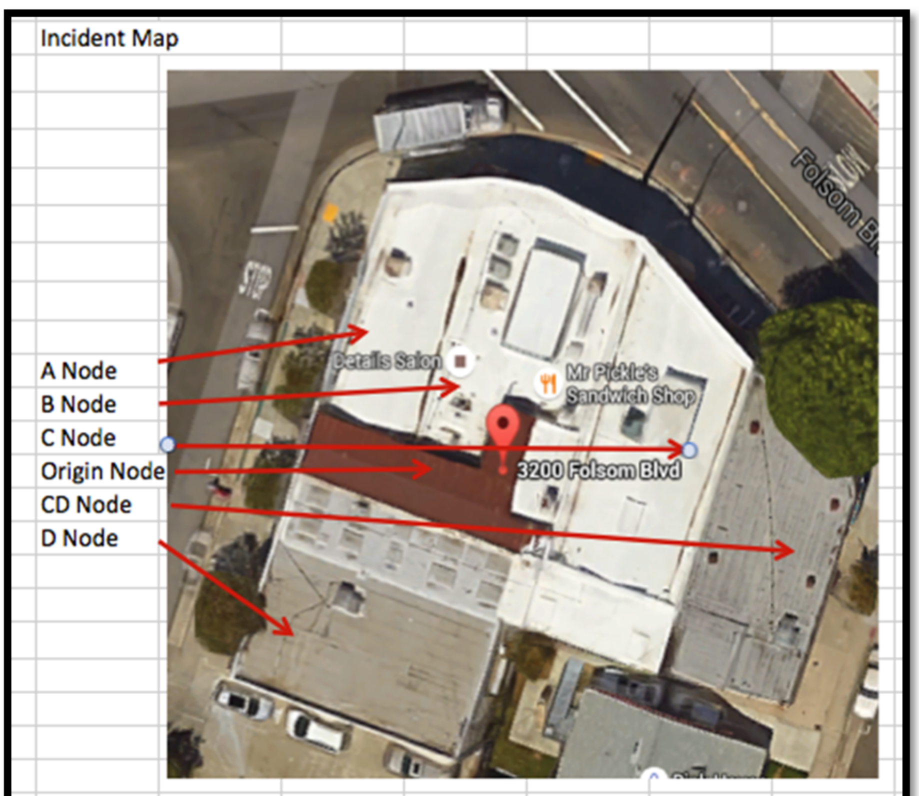
A. CASE STUDY ONE

Case study one is a fire that started in a common area of multiplex commercial building housing five separate businesses. The common area functioned as hallway that connected the businesses to a shared bathroom; therefore, it had a direct connection to each business. The fire was stopped in the common area by SFD's response model before it spread to the other units.

1. Incident Map

The incident map in Figure 3 shows an aerial view of the building with each node labeled and identified.

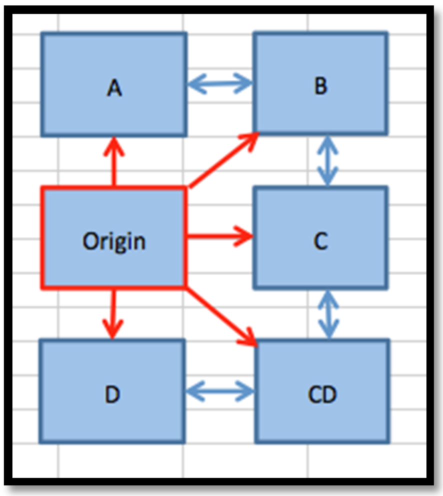
Figure 3. Case Study One Incident Map



2. Network Model

The network model in Figure 4 is modeled to a height of one from the contagious nodes, consisting of six total nodes, one contagious, and five links leading out from the contagion.

Figure 4. Case Study One Network Map



3. Quantification

Table 2 shows tangible and intangible values of each node on the network model.

Table 2. Case Study One Quantification

ΣT_V	Total Tangible value	\$2,083,195
ΣIT_V	Total Intangible Value	\$7,681,979
Σ_V	Total Value	\$9,765,174
T_L	Tangible Loss from Fire	\$70,000
IT_L	Intangible loss	\$187,791
Σ_L	Total loss	\$257,791
Σ_S	Saved	\$9,507,382
S_R	S Ratio	97%

4. Results

Case study one shows a total saved value of more than $9 million in one incident, with an "S ratio" of 97 percent, meaning that of all the value modeled on the network map, 97 percent was prevented from burning.

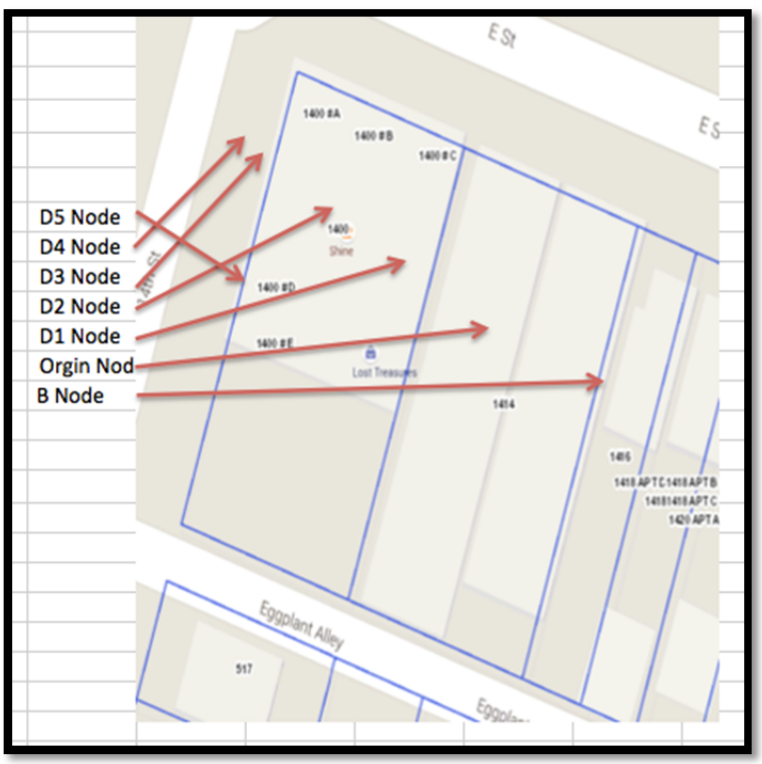
B. CASE STUDY TWO

Case study two consists of a fire in an 8000-square-foot brick commercial building that spread to its immediate neighboring building, another 8000-square-foot brick building. The fire was contained to the second building by SFD's response model; however, the original building was a complete loss and eventually torn down.

1. Incident Map

The incident map in Figure 5 shows an aerial view of the building with each node labeled and identified.

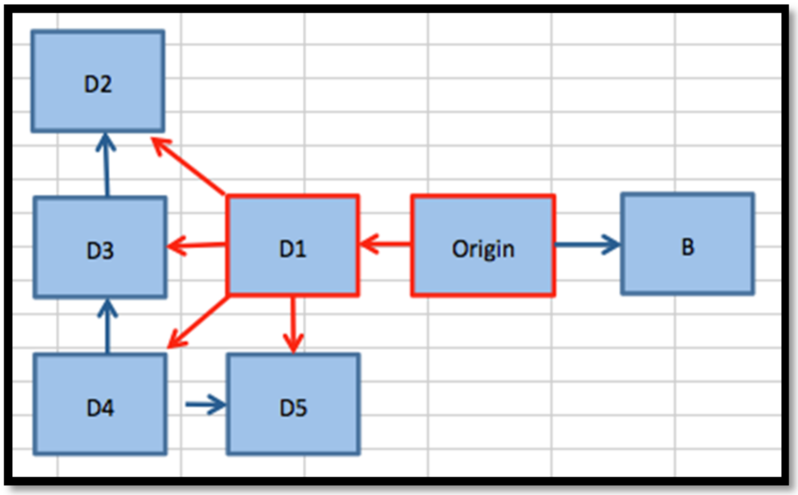
Figure 5. Case Study Two Incident Map



2. Network Model

The network model in Figure 6 modeled to a height of one from the contagious nodes, consisting of four total nodes, two contagious, and two links leading out from the contagion.

Figure 6. Case Study Two Network Map



3. Quantification

Table 3 shows tangible and intangible values of each node on the network model.

Table 3. Case Study Two Quantification

ΣT_V	Tangible value	$3,036,788.29
ΣIT_V	Intangible	$3,255,483.00
Σ_V	Total Value	$6,292,271.29
T_L	Tangible Loss from Fire	$996,410.57
IT_L	Intangible loss	$-
Σ_L	Total loss	$996,410.57
Σ_S	Saved	$5,295,860.72
	S Ratio	84%

4. Results

Case study two shows a total saved value of more than $5 million in one incident, with an "S ratio" of 84 percent, meaning that of all the value modeled on the network map, 84 percent did not burn due to firefighter intervention.

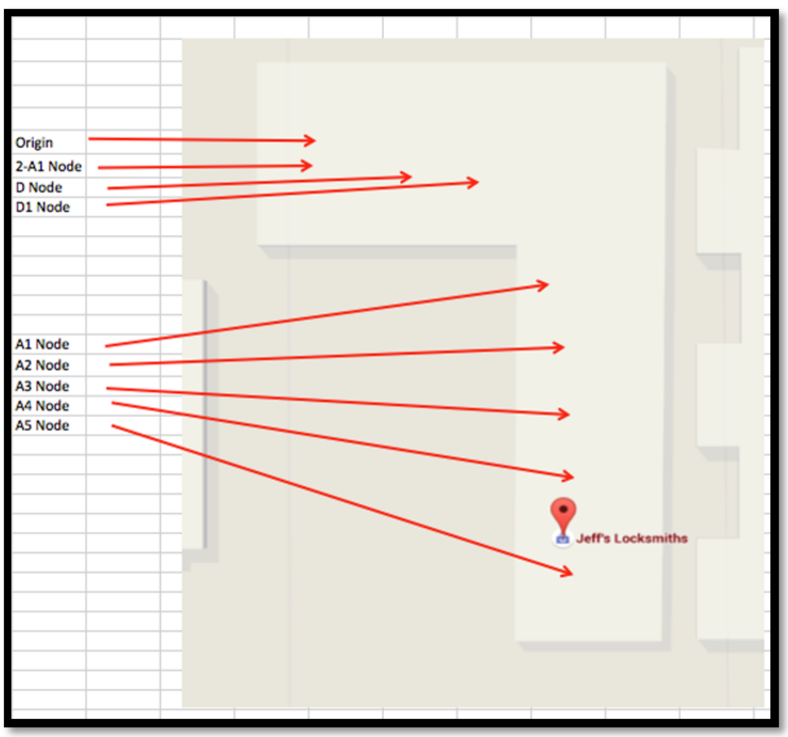
C. CASE STUDY THREE

Case study three included a fire in the corner unit of a 13,760-square-foot strip mall that housed businesses. The fire started in the corner unit and spread to the common attic. The fire was contained to the origin unit and the common attic by SFD's response model.

1. Incident Map

The incident map in Figure 7 shows an aerial view of the building with each node labeled and identified.

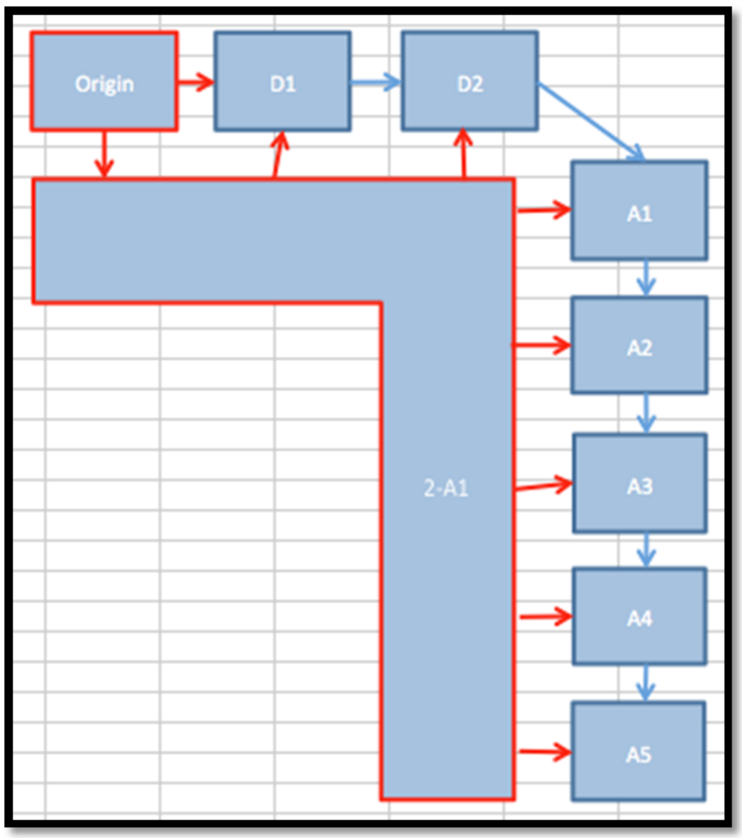
Figure 7. Case Study Three Incident Map



2. Network Map

The network model in Figure 8 is modeled to a height of one from the contagious nodes, consisting of nine total nodes, two contagious, and eight links leading out from the contagion.

Figure 8. Case Study Three Network Map



3. Quantification

Table 4 shows tangible and intangible values of each node on the network model.

Table 4. Case Study Three Quantification

ΣT_V	Tangible value	$1,887,046.69
ΣIT_V	Intangible	$2,697,411.00
Σ_V	Total Value	$4,584,457.69
T_L	Tangible Loss from Fire	$188,704.67
IT_L	Intangible loss	$934,448.00
Σ_L	Total loss	$1,123,152.67
Σ_S	Saved	$3,461,305.02
	S Ratio	76%

4. Results

Case study three shows a total saved value of more than $3 million in one incident, with an "S ratio" of 76 percent. This means that of all the value modeled on the network map, 76 percent did not burn.

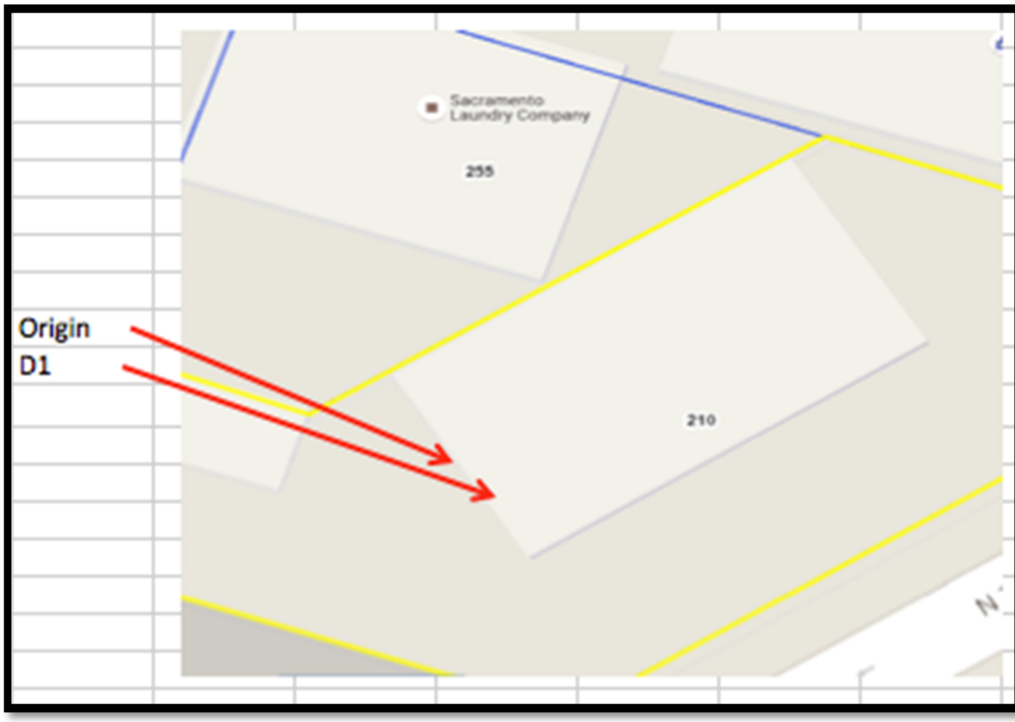
D. CASE STUDY FOUR

Case study four included a fire in a shed attached to a 5697-square-foot warehouse that served in both the manufacturing and retail sale of wooden doors. The fire started in the in the shed and spread to the warehouse. The fire was stopped at the connecting wall between the warehouse and the shed by SFD's response model.

1. Incident Map

The incident map in Figure 9 shows an aerial view of the building with each node labeled and identified.

Figure 9. Case Study Four Incident Map



2. Network Map

The network model in Figure 10 is modeled to a height of one from the contagious nodes, consisting of two total nodes, one contagious, and one leading out from the contagion.

Figure 10. Case Study Four Network Map

3. Quantification

Table 5 shows tangible and intangible values of each node on the network model.

Table 5. Case Study Four Quantification

ΣT_V	Tangible value	\$575,875.00
ΣIT_V	Intangible	\$266,391.00
Σ_V	Total Value	\$842,266.00
T_L	Tangible Loss from Fire	\$57,587.50
IT_L	Intangible loss	\$1,000.00
Σ_L	Total loss	\$58,587.50
Σ_S	Saved	\$783,678.50
	S Ratio	93%

4. Results

Case study four shows a total saved value of more than \$700,000 in one incident, with an “S ratio” of 93 percent, meaning that of all the value modeled on the network map, 93 percent did not burn.

E. SUMMARY

The previous case studies were assessed individually, while the following section will synthesize the results together, producing a quantified decrease in consequences (ΔC), and forecasted annual return on investment (ROI), and various results from network theory.

1. Delta C—What Was Saved?

A standard equation of risk is: “risk” is equal to “vulnerability” times “consequence” (R=V×C). The focus of this study is on the reduction of consequences post the commencement of an event, or Delta C (ΔC) as a measurement of value. ΔC is calculated by take the total involved (Σ_i) and subtracting the total loss (Σ_L).

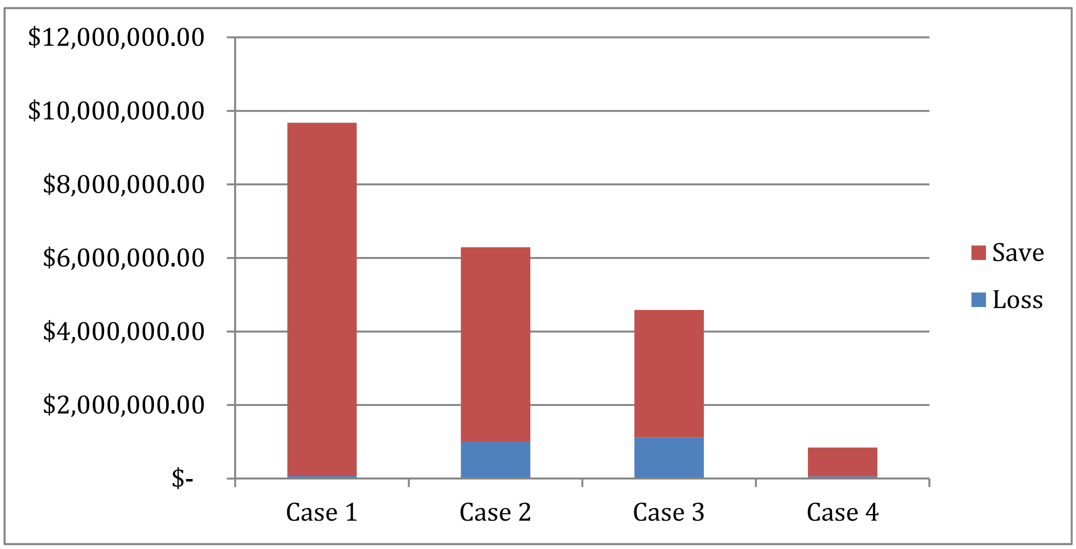
$$\Sigma_i - \Sigma_L = \Delta C$$

ΔC displayed in Table 6 and Figure 11 represents the shift in consequences from what could have happened if the network contagion were allowed to hop one additional height.

Table 6. ΔC

	Case 1	Case 2	Case 3	Case 4
Loss	$70,000.00	$996,410.57	$1,123,152.67	$58,587.50
Save	$9,608,576.16	$5,295,860.72	$3,461,305.02	$783,678.50
Total	$9,678,576.16	$6,292,271.29	$4,584,457.69	$842,266.00

Figure 11. ΔC



2. Return on Investment

Table 7 shows the forecasted ROI for SFD in 2014 based on the case studies and SFD 2014 budget. The final result was over a return on investment of more than 2000 percent.

Table 7. Modeled Return on Investment

RIO	
Total value saved	$19,149,420.40
Average value saved per building fire	$4,787,355.10
# of building fires in 2014	451
Projected Annual saved	$2,159,097,150.21
Annual Budget	96,000,000
Annual ROI	2249%

3. Network Assessment

Casting the incidents into a network model allows for an analysis of the save ratio compared to varying measures of density.

a. *S Ratio to Link Robustness*

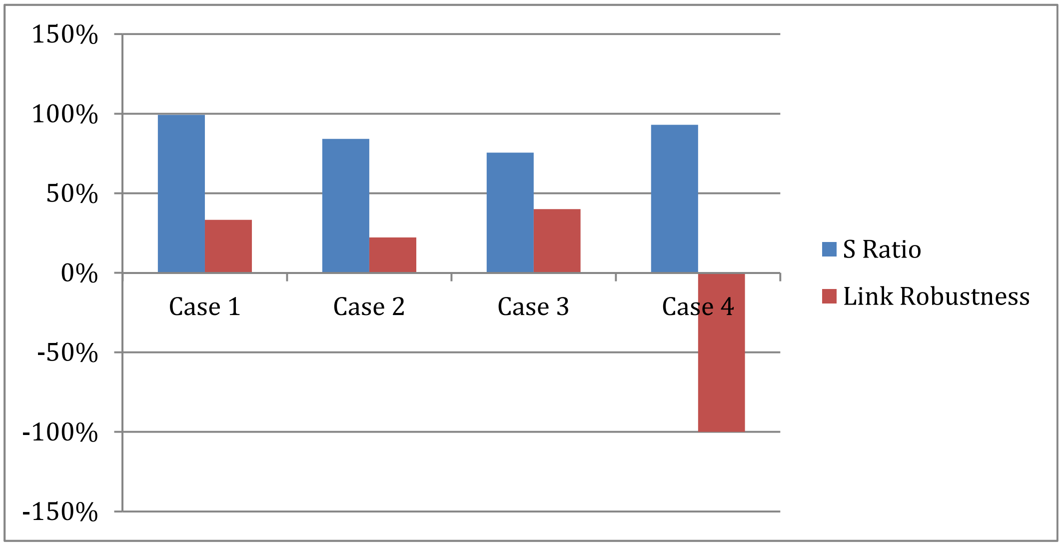
Tables 8 through 11 and Figures 12 through 15 compare the relationship between the S ratio and link robustness. Link robustness is the measure of how many links can be removed from before separating a connected network into isolated islands.[52] In other words pertaining to this study, how hard it is to isolate the contagion of a spreading fire. The more robust the network or rather the higher the number, the harder it is to isolate the contagion. The graph in Figure 12 shows the relationship between the percentages of total value saved (S ratio) to how hard it is to isolate the contagion. Excluding case study one, the results suggest an inverse relationship between link robustness and the amount of value saved. In other words, the less the link robustness, the more value is saved.

Table 8. S Ratio to Network Robustness

S Ratio to Network Robustness				
	Case 1	Case 2	Case 3	Case 4
S Ratio	99%	84%	76%	93%
Network Robustness	0.333333333	0.222222222	0.4	-1

[52] Lewis, *Critical Infrastructure Protection in Homeland Security*.

Figure 12. S Ratio to Link Robustness



b. S Ratio to Mean Degree

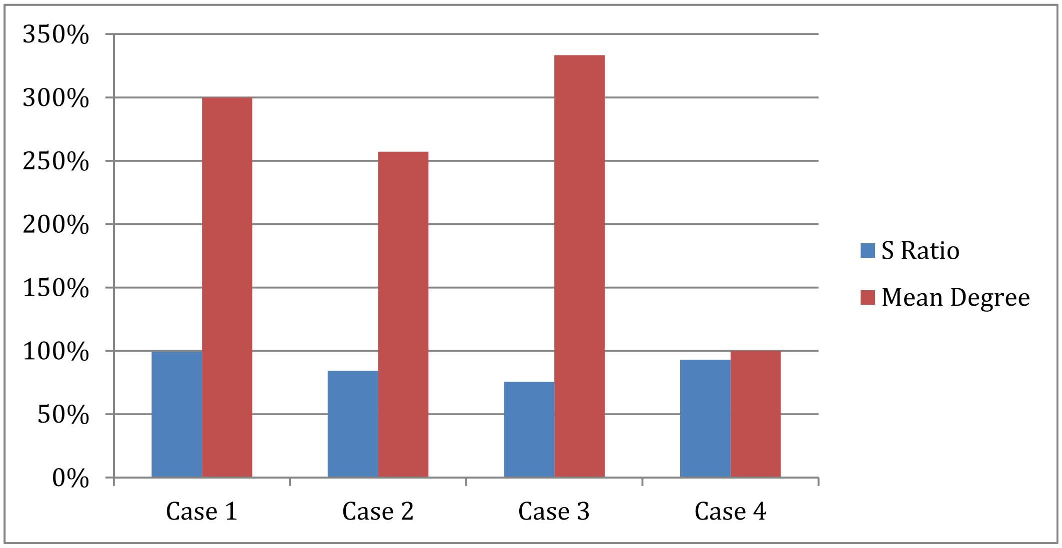
Table 9 and Figure 13 compare the relationship between the S ratio and mean degree. Mean degree represents the general connectedness of the nodes;[53] the higher the mean the degree, the denser the network. The denser the network, the easier a contagion spreads. Excluding case study one, the data suggests an inverse relationship between mean degree and S ratio. In others, the greater dense of structures or units, the less value is saved.

Table 9. S Ration to Mean Degree

S Ration to Mean Degree				
0	Case 1	Case 2	Case 3	Case 4
S Ratio	99%	84%	76%	93%
Mean Degree	3	2.571428571	3.333333333	1

[53] Ibid.

Figure 13. S Ratio to Mean Degree Graph



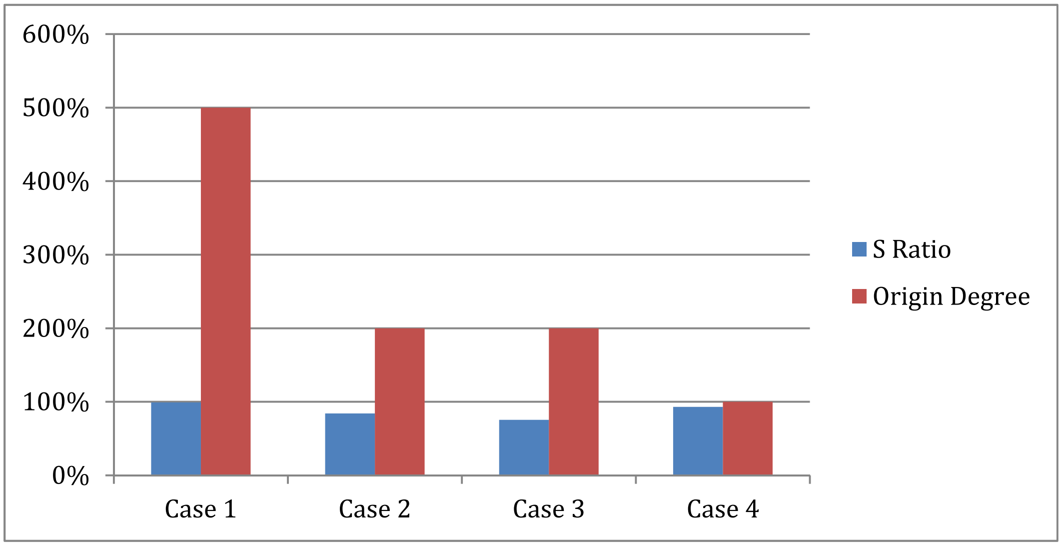
c. S Ratio to Origin Degree

Table 10 and Figure 14 compare the relationship between the S ratio and origin degree. Origin degree is number of links leaving the origin of the contagion, or rather a measurement of how connected the first burning unit to other exposures. Excluding case study one, the data suggests an inverse relationship between origin degree and S ratio. In other words, the more connected fire burning unit is, the less value is saved.

Table 10. S Ratio to Origin Degree

S Ratio to Origin Degree				
0	Case 1	Case 2	Case 3	Case 4
S Ratio	99%	84%	76%	93%
Origin Degree	5	2	2	1

Figure 14. S Ratio to Origin Degree Graph



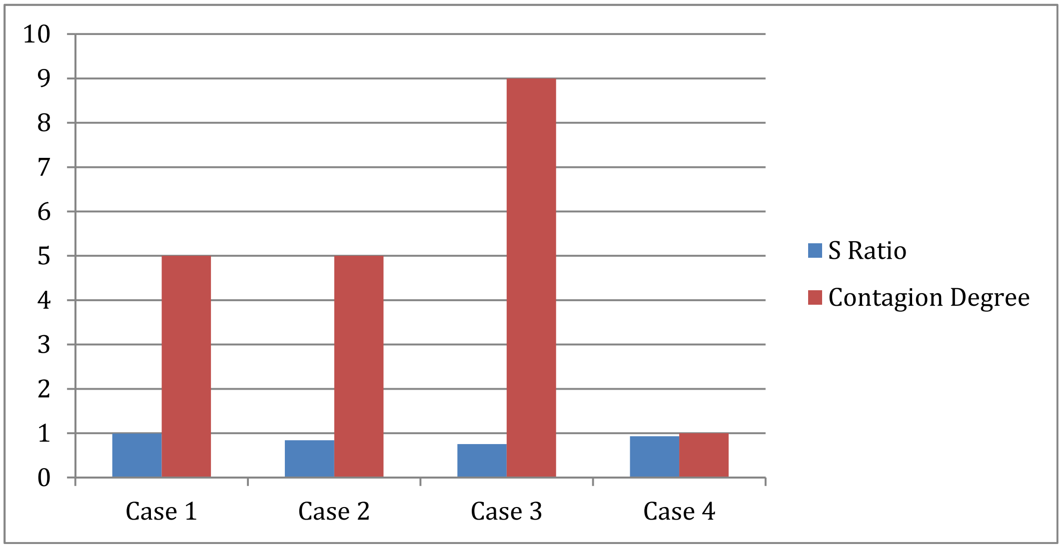
d. S Ratio to Contagion Degree

Table 11 and Figure 15 compare the relationship between the S ratio and contagion degree. Contagion degree is number of links leaving the final contagion, which includes all burning units. Excluding case study one the data suggests an inverse relationship between contagion degree and the S ratio. The more connected the contagion is, the less value is saved.

Table 11. S Ratio to Contagion Degree

S Ratio to Contagion Degree				
0	Case 1	Case 2	Case 3	Case 4
S Ratio	0.992767531	0.841645326	0.755008608	0.930440621
Contagion Degree	5	5	9	1

Figure 15.   S Ratio to Contagion Degree Graph



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IV. CONCLUSIONS AND REFLECTIONS

QTN demonstrates that calculating the saved ratio is not only possible, but it is also a better indicator of fire department performance than the current measurement of tangle loss. QTN uses a two-step process: “identify” using network theory and “quantify” using economic theory. The case studies demonstrate the methodology applied to structure fires in Sacramento, California with results that demonstrate a shift in consequences due to the response model and a return on investment measurement defined as the saved ratio.

When simply looking at the amount of tangible fire loss, it is hard to get an accurate indication of performance without knowing how much was at risk. It is classic denominator blindness. By quantifying the total value of what was at risk and comparing it to what was lost gives a much better measure of performance.

A. CONCLUSIONS

Three major conclusions can be made from this study. The first conclusion is that methodologies from the real estate and economic industries can be used to quantify tangible and intangible value involved in structure fires. The second conclusion is network theory can be used to map the potential spread of a fire as contagion, allowing the user to identify what structures were saved or lost. The third conclusion is that it is possible to estimate the ROI added to the community from a fire suppression response model.

IRCA and REIM have reproducible results in a monetary value. Typically, the fire service only attempts to estimate the tangible value of what was burned. QTN provides the tangible value of structures as a whole and the intangible value of the business, which paints a better picture of what was at risk and what was saved.

In addition, network theory provided a tool to map, articulate, and “prove the negative.” The ability to explain the height of the network, define the limits of links and nodes, and map the contagion served as the required existential statement required to “prove the negative.” Finally, the combination of network theory to “identify” and

IRCA/REIM to "quantify" produced a reproducible total monetary value of what was saved and lost after a fire incident.

B. INITIAL RESPONSE TO QTN

Since the start of researching the how to quantify the negative, I have presented on the topic many times, including to Sacramento's city manager at the western regional economics conference and at two California State Fire Marshal chiefs classes. During the presentations, I can see the audience move from a state of curiosity, to epiphany, and finally to determination. The determination is to change the way they think about and communicate their organization's value. As a result, I have started a pilot study in Sacramento to quantify the amount saved on each fire. When addressing the media and city council, SFD's public information officer and chiefs no longer focus on the building that burned but rather on the buildings and business that were saved. QTN has provided a framework and platform for communicating the fire department's value in a way every citizen can understand: dollars. Four other departments in the region have expressed serious interest in implementing a similar study and requested a meeting on how to proceed. As a result, the following section provides a brief guide to application.

C. APPLICATION OF QTN

The difficult part of QTN is not the math; the math is a simple equation and ratio. The difficult part is changing the public safety mindset, changing the understanding of the value of a fire service. This change in thinking leads to a necessary change in policy. In achieving this understanding and in working in furtherance of these calculations, agencies can start policy reform by using a form of the following vision and mission:

Vision: To change the dialogue of public safety by recognizing that the worth of a fire department is greater than a calculation of loss and that the worth of a fire department is more accurately represented by including what is saved.

Mission: Establish a standard to record and report the value of what is at risk and the value of what is saved on each fire, including tangible and intangible values.

Objectives:

1. Develop a standard procedure to establish a total value for what is at risk based on structural replacement value and an economic impact report.
2. Use ratio scores to measure and monitor performance, correlating performance to response times and to staffing levels.
3. Acknowledge that data must be gathered in a standardized way, and then it must be analyzed and transformed into information to be beneficial.
4. Input data and results into a central database.
5. Provide management data and information on set schedules (e.g., for press releases and city council meetings) to show quantification of worth to the community and to justify an accurate budget.

D. DISCUSSION

The results of QTN show a significant decrease in consequences due to a fire suppression response. A decrease in consequences due to fire suppression operations may have intuitive and obvious prior to the study, but the amount was in question. Some policy makers may argue the cost of fire suppression greatly exceeds the decrease in consequences, producing a negative ROI, while others can argue the opposite. The results from QTN may help settle the agreement by producing monetary values. The summative results of the case studies certainly showed a positive ROI at more than 2000 percent.

The author's intent is not to use QTN to simply justify budgets but as rather a tool to size budgets correctly, to understand consequences of adjusting budgets, and use it as a comparative performance tool. The S ratio, as normalized result, provides a performance measure from year to year that could show the effect of policy or budget changes. For example, if an agency had an average S ratio of 95 percent each year prior to a policy change and fell to an S ratio of 90 percent after a policy change, the agency has a comparative measure to see the effects of the new policy. The agency could then compare the total saved each year to estimate the cost or value added of the new policy.

The results tend to follow a trend; the denser the buildings and the more connected the original fire the lower the S ratio. However, case study one did not adhere to this trend. With a highly connected and dense network and the highest S ratio, case study one seems to be a great fire stop. Low response time and a crew with higher than

normal area familiarization may have influenced this case study. The incident in case study one was very close to a fire station that was staffed by a longtime established crew at the time of the fire. These factors may have overwhelmed the network trends and resulted in extremely an early fire stop regardless of the density and connectedness of the network. Hopefully, the demonstration of this process will provide a first step of a paradigm shift in thinking for all of homeland security: stop focusing on what was lost, and start focusing on what was saved.

E. LIMITATIONS

QTN has many possibilities, and the fire service participates in many activities. However, the bounds of this study are very specific to make the research and conclusions manageable.

1. Network Theory

Network theory does a great job mapping a two dimensional map of an incident. However, it can become challenging when mapping a three-dimensional map without specialized skill and software. For example, case study three included a common attic, which is technically a second story requiring a three-dimensional map. A high-rise building with multiple stories will require a complex nomenclature system and probably multiple network maps for each floor.

2. Tangible

The IRCA uses *utility replacement* to estimate a value, not *reproduction replacement*. For example, the replacement of historical building would be estimated how much to rebuild a building that met the same utility, not a replication of the building. This can be a sort coming when assessing historic or unique buildings that may have limited utility but have great sentimental value to the community.

3. Intangible

The intangible value results from the REIM have a number of limitations. First, the loss of the business is estimated at one year; however, the reality may be much

longer, as such in case study two where the building was torn down. However, the standard of one year was used consistently in each study for compatible outcomes. In addition, the REIM makes a number of assumptions including: REIMs look backward at historical data, not forward to projected data; there are no supply constraints; there is no input substitute in response to the change in output; and all prices are stable for the time frame of the study.

4. Potential Misuse of QTN

All models as wrong on some level, as they are simple representations of reality. However, regardless of their inadequacies, some models are useful. Like all models, QTN has shortcomings as a model representation of reality, but when used correctly it is useful as a performance measure to estimate ROI in post incident event. However, QTN will only be useful if used in a reasonable, unbiased manner to seek the truth, not support a particular narrative. Due to QTN's reliance on accurate data, results could be swayed by cherry picking data in order to support a biased narrative. It is up to the user to apply QTN results in a reasonable manner in order support the truth.

In addition, QTN is not intended to leverage resource deployment or standards of coverage decisions alone. If used at all as pre-incident tool, it should be used as an adjunct to current methodology.

F. RECOMMENDATIONS OF FUTURE RESEARCH

This study of QTN is focused on a small sample of structure fires in the urban environment with more of a focus on the methodology than the results. Future studies should include a larger sample to expand the network theory analysis and quantitative results further. Ultimately, for best results, QTN should be implemented and used continuously in an agency in order to compare results year to year. In addition, QTN applied towards emergency medical services, special rescue services, hazardous materials response, and arson investigation could be great value as a performance measure to fire service.

1. Expanded Use

The problem on focusing on just loses seems to be a standard in the public safety. Law enforcement reports crimes committed, not the value of crimes prevented or mitigated. Likewise, the Department of Homeland Security tends in general to report on criminals detained but not the value of preventing the potential destructive activities of the criminals. The general framework of QTN to identify and quantify events in conjunction with specific methodologies for each domain can provide a catalyst to change the dialogue from "costs" to "value added" for all public safety organizations.

Below are a number of organizations and how they could potentially use the concept of QTN.

a. Law Enforcement

The broad concept of QTN could be applied in law enforcement to quantify the value of arresting a criminal. The arrest effectively removes the criminal from access to future victims. The Law Enforcement agency could then identifying and quantifying the value of future crimes. For example, if a serial killer is captured with evidence of the next victim or an established pattern of victimization, network theory could be used to identify the next victims and the FDA value of human life could be used to quantity the total value of lives saved. Then, the total value of lives saved could be weighed against the cost of the law enforcement operation.

Transportation Security Administration If the Transportation Security Administration stops a terrorist attack on a plane, QTN could provide a value on the operations. Using network theory to identify the target or targets (e.g., aircraft and passengers), Transportation Security Administration could use Transportation Department's value of life and aircraft replacement to quantify the total value saved by the operations. In addition, TSA could use economy impact theory to estimate the value of potential loss of business due to a success attack on an aircraft. The total value could then be weighed against the cost of the TSA operation.

b. Coast Guard

The U.S. Coast Guard could use QTN to identify and quantify the value of preventing illegal contraband or preventing a terrorist attack.

c. Border Patrol

The apprehension of a criminal at our nation's borders can have a significant effect on the economy, including the prevention of criminal and terrorist acts. QTN may provide a basis to assign a nominal amount to the value added to the U.S. by preventing criminal into our country. Network theory can be adopted to link and identify planned criminal activity while REIM and Transportation Department's value of life figures could be used to evaluate the prevented crimes.

d. Federal Emergency Management Agency

Intervention and mitigation of major disasters has a momentous benefit to society and our nation. Very similar to the use of QTN in structure fires, the Federal Emergency Management Agency could link the next probably event in majors disasters had it not responded and assign a value to what was at-risk, what was saved, and what was lost.

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V. REFLECTIONS

One accurate measurement is worth a thousand expert opinions.

—Admiral Grace Murray Hopper

Public safety agencies CAN and SHOULD focus on what was saved versus what was lost. Simply reporting loses during an incident tells only part of the story, like trying to estimate the size of an iceberg by only looking at what is visible above the water's surface. The general framework and prescriptive methodology laid out in QTN is small step toward looking at incidents holistically by mapping out the fire's potential to grow if not suppressed. Thus, QTN can lead to a better understanding of how effective current response models are and the positive or negative effects of policy changes.

A. FUTURE WORKS

Further studies may reveal a standard model to deploy resources based on the mean degree of a network and the mean value of each node. The use of network theory to model incidents can provide a measurement of susceptibility to fire spread based on density. Fires tend to follow a power law when spreading across dense networks, meaning that the growth of a fire is exponentially faster in denser networks. Comparing the saved ratio to response times and network density may show that a one-minute delay in response in a dense city is much more costly than a one-minute delay in response in a suburban environment. This observation may be generally intuitive, but QTN can provide a dollar amount of how much more costly a delay in response may be based on the environment.

The flexibility of the network model allows the user to adopt multiple variations of the study. For example, I defined a link as proximity of 10 feet or less. However, some environments, based on construction type, may be better suited with a definition of 30 feet or less and so on. Also, I limited my study to a network height of "one" to focus on what would happen if a response was delayed or less effective. However, a study of what

would happen if no response was available, such as the cripplingly of the fire department during a major earthquake, the network height could be expanded.

In addition, QTN can serve as tool to weight the impact and importance of incidents. Typically, fire departments respond to more emergency medical services (EMS) incidents than fire incidents. Both types of calls are weighted equally in the National Fire Incident Reporting System, suggesting that the fire service should begin to shift resources from fire suppression to EMS purely based on frequency of events. However, simply looking at the frequency of events may overlook the fact that some incidents have an overall greater impact on the community even though their occurrence is rare. QTN can provide a qualitative measure of incidents based on value saved opposed to frequency of occurrence. The fire service may find that even though fire calls represent a small percentage of total calls, they do represent the largest impact to the community. This qualitative measure can act as a guide to resource distribution when trying to maximize return on investment to the community.

B. CLOSING

QTN has been a long journey. It started in 2008 when I was asked to do a study on my agency to estimate the impact of a 20 percent budget cut. As I poured over the numbers of 240,000 incidents, I started to realize that the fire service did not collect the correct data. We only recorded what was lost on fires resulting in only half of the equation. “Lost out of out of how much total?” was the real question I had. For example, if we lost \$5 million out of \$5 million at risk, we did a pretty bad job. There would have been minimal difference if we responded or not. However, if we lost \$5 million out of \$90 million at risk, we did a great job. But nowhere did we record how much was at risk or how much we saved. In fact, we had no way of even calculating those numbers. So my journey began how to identify and quantify what was at risk during a fire so I can calculate what was saved.

Ultimately, I never imagined a merger of economic impact theory and inductive replacement cost cast into a network model, but the solution provides a solid methodology for most fire incidents. And the general framework of “identify and

quantify" can be adapted to other types of incidents and domains such EMS calls or law enforcement.

Finally, public safety agencies need to change the discourse of what value they bring to community. The fire service's greatest value to the community is what it saves, not what is lost; however, the fire service's national incident reporting standard only records damage. This mindset is based on the 1973 report *America Burning*, a study focused on fire loss and firefighter deaths. The report was a critical first step in defining the fire problem in America and a catalyst for the U.S. Fire Administration, the National Fire Academy, and the National Fire Incident Reporting System.[54] Nonetheless, major advancements studying the effectiveness of the fire service have never evolved past focusing on what was lost.

The next logical step would have been to report on what was saved, but that has never happened—until now. As a result, the fire service deployment models are based on response times, experts, and antidotes as opposed to true measurements of effectiveness such as the save ratio.

[54] National Commission on Fire Prevention and Control, *America Burning* (Washington, DC: National Commission on Fire Prevention and Control, 1973), https://www.usfa.fema.gov/downloads/pdf/publications/fa-264.pdf.

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